Caribbean Science Workshop
University of Puerto Rico, Rio Piedras
September 11, 2014

Non-PRASA Drinking Water Research Studies

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Looking for Funding

Proposal Date	Potential Funding Source	Outcome	Proposal Title
Nov. 10, 2010	Pathfinder Innovation Project Proposal	Not Awarded	Collaborative Research on Small Community Health Effects before and after Installation of Innovative Treatment Technologies Designed to Remove Persistent Waterborne Pathogens from Imperiled Drinking Water Supplies in Puerto Rico
May 7, 2012	Regional Sustainable Environmental Science Proposal	Not Awarded	Collaborative Research on Small Community Health Effects before and after Installation of Innovative Treatment Technologies Designed to Remove Persistent Waterborne Pathogens from Imperiled Drinking Water Supplies in Puerto Rico
May 18, 2012	Regional Applied Research Effort (RARE) Proposal	Awarded	Evaluation of the Effectiveness of UV Disinfection over Time for Inactivation of Waterborne Pathogens in Surface and Groundwater Supplies in Non-PRASA Communities in Puerto Rico
Jan. 7, 2014	CDC Innovation Fund Proposal	Not Awarded	An Intervention Trial of Biosand Filters to Reduce the Burden of Diarrheal Illness in Rural Communities in Puerto Rico
May 28, 2014	Regional Applied Research Effort (RARE) Proposal	Being Reviewed	Evaluation of Renewable Water Treatment and Monitoring Technologies to support Communities in Puerto Rico with the Operation of Non-PRASA Drinking Water Systems

EPA Region 2 RARE Project

Small Community UV Disinfection Research

- A Regional Applied Research Effort (RARE) Project was awarded by EPA Region 2 in April of 2013 entitled "Evaluation of the Effectiveness of UV Disinfection over Time for Inactivation of Waterborne Pathogens in Surface and Ground Water Supplies in Non-PRASA Communities in Puerto Rico"
- EPA completed UV disinfection studies to determine the effectiveness of low-pressure UV lamps on inactivation of MS2 (a viral surrogate) in groundwater and surface water supplies at La Sofia and Apeadero in September 2013 and April 2014

Collaboration on Contracts and Research Studies

Contract Dates	Contract Funding	Project Officers	Work Assignment Title
June 1, 2011 to May 31, 2012	T&E Contract WA2-04	Craig Patterson	Technical Support to Evaluate the Cost and Performance of Innovative Water Filtration Technologies Integrated to Remote Telemetry Systems in High-Turbidity Public Water Systems in Tropical Environments
June 1, 2013 to May 31, 2014	T&E Contract WA4-16	Cristina Maldonado, Craig Patterson	Evaluation of the Effectiveness of UV Disinfection over Time for Inactivation of Waterborne Pathogens in Surface and Groundwater Supplies in Non-PRASA Communities in Puerto Rico

Study Dates	EPA Research	Researcher	Research Study Title
July 1-Aug. 14, 2009	Student Services Contract	Gerald Velaquez-Rivera	*E. Coli* Removal Efficiencies in a Slow Sand Filter using Various Coagulants (Chitosan, Ferric Chloride, Alum)
Feb. 3-Apr. 4, 2013	Regional Research Partnership Program	Cristina Maldonado	Combining Ultraviolet Disinfection with Chlorination for Protection of Human Health

RARE Project Approach

Perform a collaborative research study with the InterAmerican University (IAU) of Puerto Rico to investigate disinfection technologies.

- Design source water delivery, pre-filtration and disinfection systems, based on community location and water quality characteristics
- Purchase, ship and install equipment and supplies at two different Non-PRASA systems
- Document and compare the ease of use and O&M costs of each treatment system, as they are affected by source water conditions over a six month period
- Determine treatment effectiveness of UV disinfection

Expected Products

- Guides on the installation, ease of use, and effectiveness of UV disinfection for Non-PRASA drinking water systems and similar systems in other tropical environments
- Conceptual diagrams of UV disinfection system design alternatives for inactivation of chlorine resistant pathogens
- Improved health for people living in two communities served by Non-PRASA systems by providing clean and safe drinking water using a low cost multi-barrier solution
- Scientific articles and conference proceeding papers will disseminate field study results through libraries and computerized literature searches

Small System Technology Transfer

Presentation Date	Event	Location	Presentation Title
Mar. 11, 2011	IAU's 9th Cecia Biennial Symposium on Potable Water Issues in Puerto Rico	Bayamon, Puerto Rico	Household Devices for Safe Drinking Water in Small Communities
Aug. 30, 2011	8th Annual Workshop on Small DW Systems	Cincinnati, Ohio	What is Puerto Rico Doing to Help Small Systems Achieve Compliance?
Feb. 28, 2013	IAU's 10th Cecia Biennial Symposium on Potable Water Issues in Puerto Rico	Bayamon, Puerto Rico	UV Treatment for Small Systems
May 22, 2013	EWRI World Environmental & Water Resources Congress 2013	Cincinnati, Ohio	Lessons Learned from the Installation of Several Experimental Water Treatment Systems in Rural Puerto Rico
June 2, 2014	EWRI World Environmental & Water Resources Congress 2014	Portland, Oregon	Evaluation of UV Disinfection for Inactivation of Waterborne Pathogens in Surface and Groundwater Supplies in Non-PRASA Communities in Puerto Rico
Sept. 11, 2014	Caribbean Science Workshop	San Juan, Puerto Rico	Non-PRASA Drinking Water Research Studies

Disclaimer

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for external publication. Any opinions expressed are those of the author (s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Why UV Treatment?

Benefits of UV

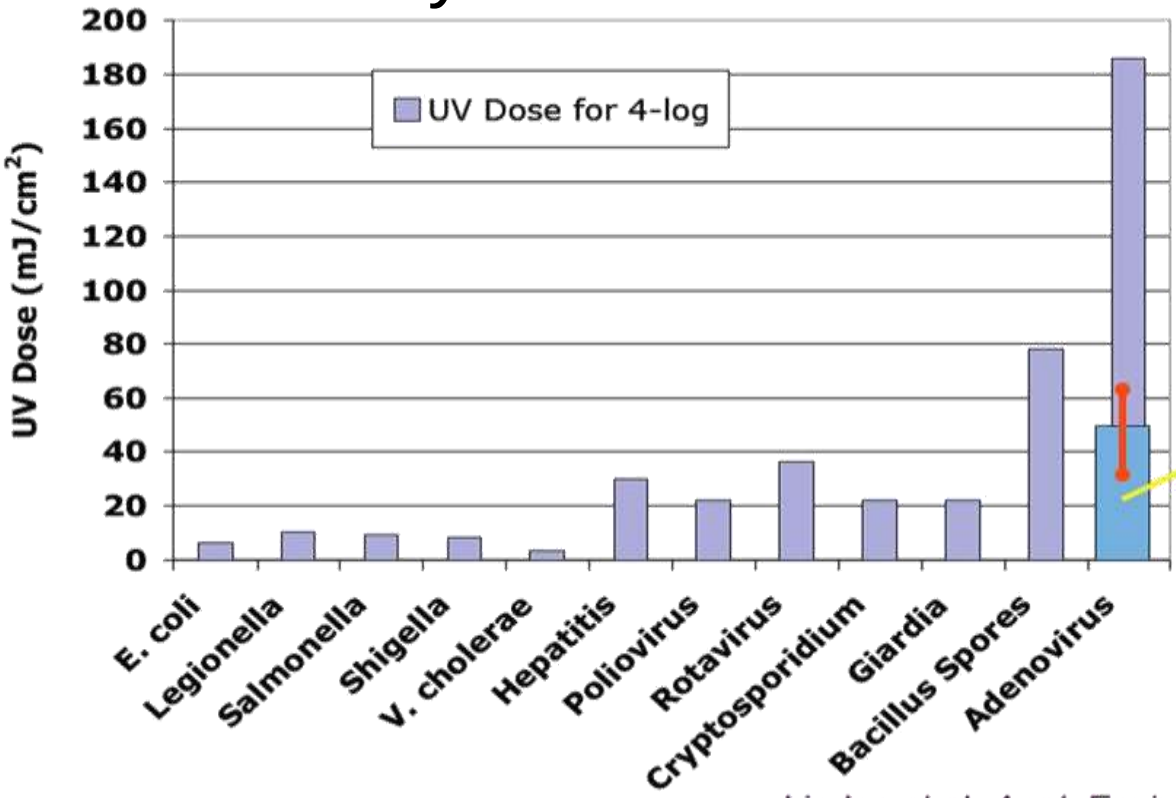
- No disinfection byproduct (DBP) concerns
- No waste streams
- Low chemical management & safety risks
- Real-time monitoring (for large systems)
- Requires little operator attention (not always)
- Small footprints & retrofits

Why UV Treatment?

Disadvantages of UV

- Lamps and quartz sleeves are fragile
- Lamps contain hazardous materials (mercury)
- A secondary disinfectant is needed
- Electrical costs (only 110v for small systems)

Why UV Treatment?



Linden et al. *Appl. Environ. Microbiol.* 2007

UV-LP Inactivation of Several Pathogens

Target Pathogens	Log Inactivation							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

[1] 40 CFR 141.720(d)(1)

UV Inactivation Doses under EPA Regulations

Project Locations

A two-hour commute

CECIA at IAU, San German

Pressure Sand/UV System at LaSofia

Drum Filtration System at El Real

Waterboy/UV System at Apeadero

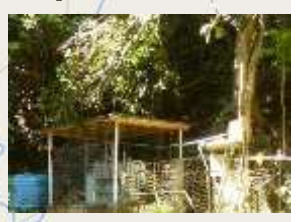
MAP Source: National Atlas of the United States

Project Locations

La Sofia

El Real

Apeadero



Who would want to live here?

View from Apeadero

It is amazing what Non-PRASA communities can construct in extremely difficult terrain

Non-PRASA Surface Water Systems

An operator rakes leaves from a surface water pool created by damming a creek in the rainforest

Water storage tank and screened intake pipe at the source

Non-PRASA Storage Tanks and Tablet Chlorinators

Operators replace chlorine tablets to provide a chlorine residual after contact time in water storage tanks

Aboveground Rural Conveyance Piping

Whatever works…









Non-PRASA Community Health Issues

Surface Water Quality in Rural Puerto Rico

Flashy rainwater with local carriers of chlorine-resistant *Cryptosporidium parvum*

Getting There…

The Road to El Real

Drum Sand Filters at El Real

Installing two drum sand filters in series for surface water studies

Sieving Sand for the Slow Sand Filters

A sieve used to prepare a thick layer of fine sand with the prototype at an EPA research facility in Cincinnati, Ohio

Lessons Learned

Installation in the Field is No Match for Fabrication in a Machine Shop

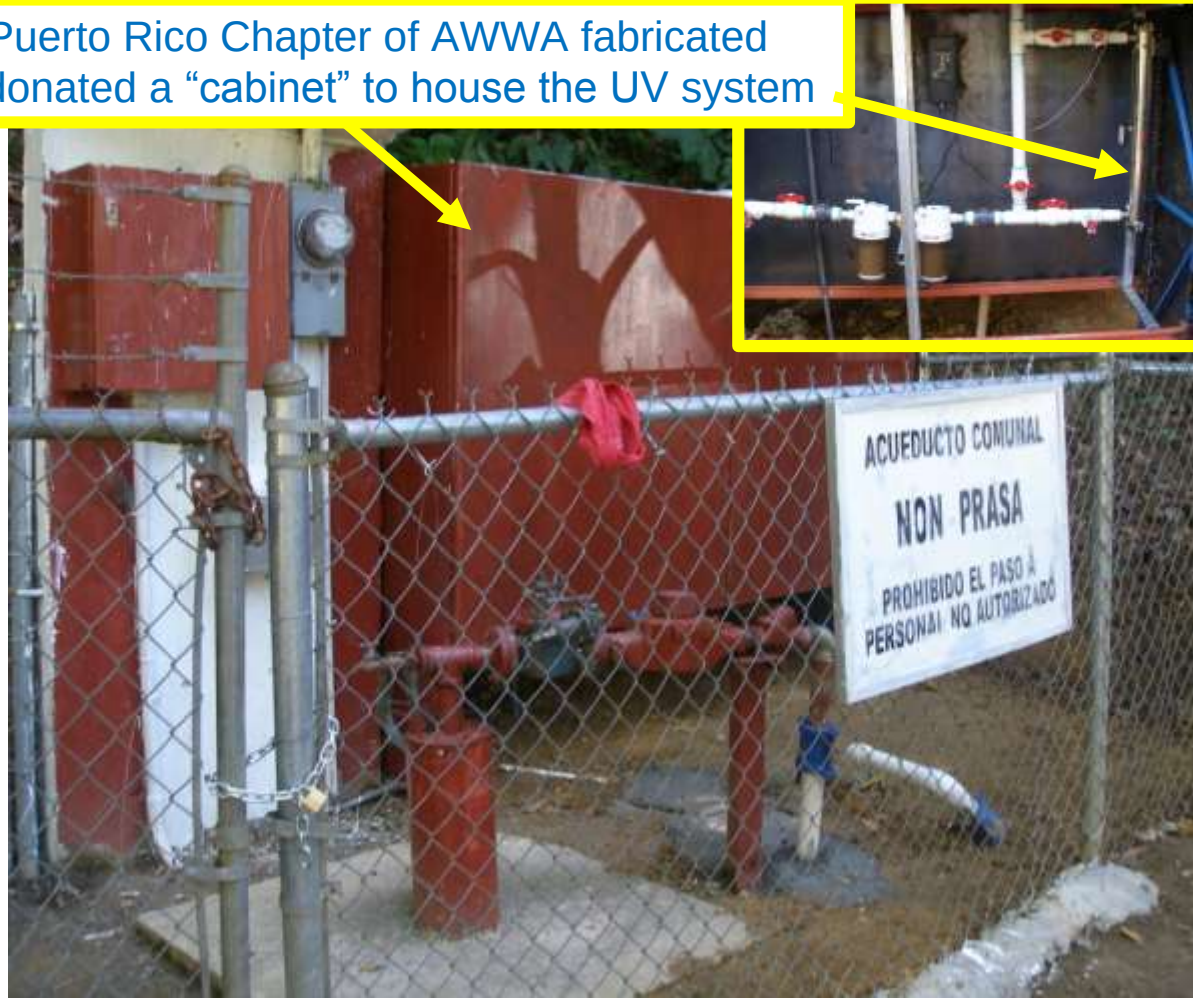
Used drums caused leaks to occur at piping connections with damaged lids and lid seals

Getting There…

The Road to La Sofia

Non-PRASA Water System at La Sofia

The Puerto Rico Chapter of AWWA fabricated and donated a “cabinet” to house the UV system



Before 2009

After 2011

Installing a Pressure Sand Pre-Filter at La Sofia

Installing Cartridge Pre-Filters in Parallel at La Sofia

Non-PRASA Water System at La Sofia

Before 2011

After 2014

Cost of Non-PRASA Water System at La Sofia

La Sofia Well Water		
Vendor	**Item**	**Cost**
	Well Pump (Already Installed)	$0
Trojan	UV Max J System (45 GPM)	$2,300
GE	2 Cartridge Pre-Filter Housings	$134
Dayton	Low-Pressure Sand Pre-Filter (28 psi)	$450
Pentair	High-Pressure Sand Pre-Filter (75 psi)	$920
Home Depot	Plumbing Components: Pipes, Valves and Fittings	$400
	Total Cost	**$4,204**

Vendor	Replacement Parts	Cost
Trojan	UV Power Supply	$590
Trojan	UV Sensor	$270
Trojan	UV Bulb	$245
Trojan	UV Quartz Sleeve	$62
GE	Cartridge Pre-Filter (30 micron)	$17

Getting There…

The Road to Apeadero

Non-PRASA Water System at Apeadero

Before 2009 **After 2014**

US Filter WaterBoy System at Apeadero

As Delivered

Installing the Electrical and Water Lines at Apeadero

The main power line was hit by a falling tree limb

Installing the Multi-Media Filter at Apeadero

Carrying and installing 850 pounds of filter media was no small task

Installing the Backwash and Chemical Feed Tanks

US Filter WaterBoy System at Apeadero

As Installed

Installing Cartridge Filters and UV at Apeadero

Cost of Non-PRASA Water System at Apeadero

Apeadero Surface Water		
Vendor	**Item**	**Cost**
Trojan	UV Max J System (45 GPM)	$2,300
GE	Cartridge Pre-Filters in Parallel (30 micron)	$134
Siemens	Conventional Treatment System with Tanks, Media and Hoses	Donated
Home Depot	Plumbing Components: Pipes, Valves and Fittings	$125
	Total Cost	**$2,559**

Vendor	Replacement Parts	Cost
Trojan	UV Power Supply	$590
Trojan	UV Sensor	$270
Trojan	UV Bulb	$245
Trojan	UV Quartz Sleeve	$62
GE	Cartridge Pre-Filter (30 micron)	$17

RARE Project Schedule

- Selected demonstration sites:
  - La Sofia – Groundwater
  - Apeadero Arriba – Surface water
- Two series of tests conducted:
  - September 2013 – System installation and testing
  - April 2014 – System maintenance and testing

Test Runs

- Test Organism - MS2 bacteriophage as a surrogate for viruses
- Run three flow rates for each system (based on the maximum flow rate achievable given the source water flow rate and system pressures)
- Collimated beam study conducted by BioVir Laboratories on the same MS2 stock and with water shipped from each site
- UV Transmissivity measured on the water in the systems

UVT Results

La Sofia Well Water		
Date	**Time**	**UV Transmittance**
9/25/13	**2:00 PM**	96.5%
9/25/13	**3:37 PM**	99.3%
9/26/13	**5:04 PM**	98.3%
9/26/13	**5:50 PM**	95.5%
4/8/14	**2:00 PM**	99.3%
	Average	**97.8%**
	Range	**95.5% to 99.3%**

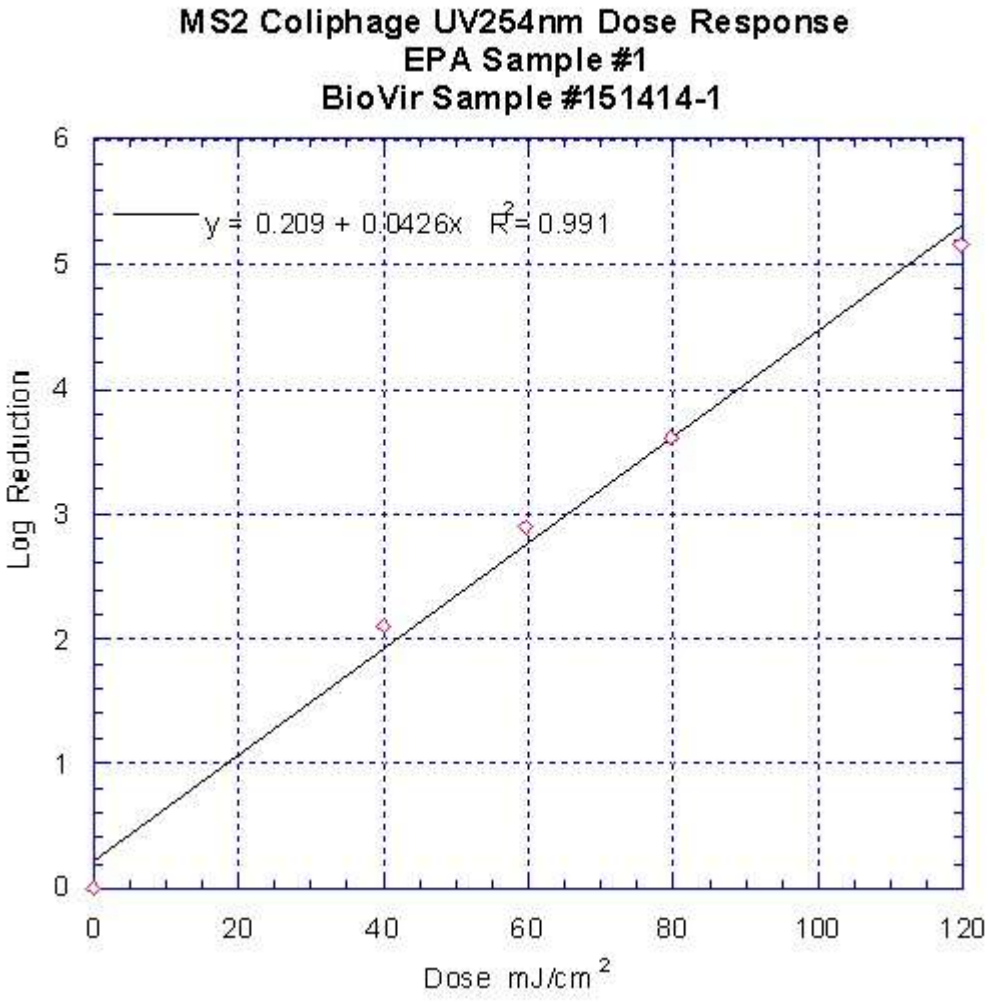
Apeadero Surface Water		
Date	**Time**	**UV Transmittance**
9/28/13	**2:05 PM**	97.3%
9/28/13	**2:22 PM**	94.4%
9/29/13	**12:12 PM**	97.0%
9/29/13	**2:18 PM**	96.1%
9/29/13	**3:00 PM**	94.6%
9/29/13	**4:12 PM**	96.6%
4/9/14	**5:55 PM**	90.1%
	Average	**95.2%**
	Range	**90.1% to 97.3%**

MS2 Studies at La Sofia

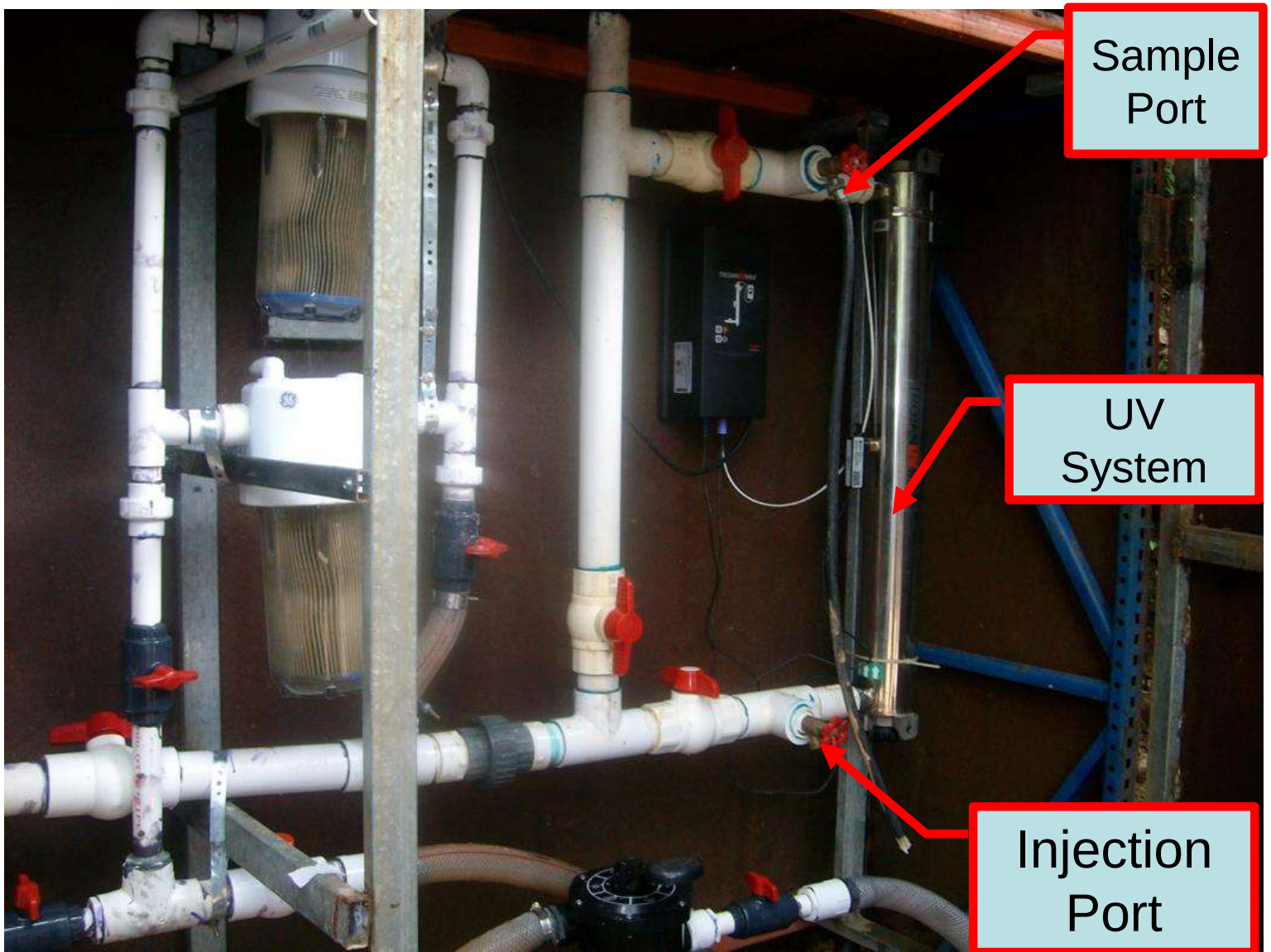
Long days of MS2 and UVT sample collection

La Sofia Well Water

Collimated Beam Results



Configuration for Sept 2013 Tests

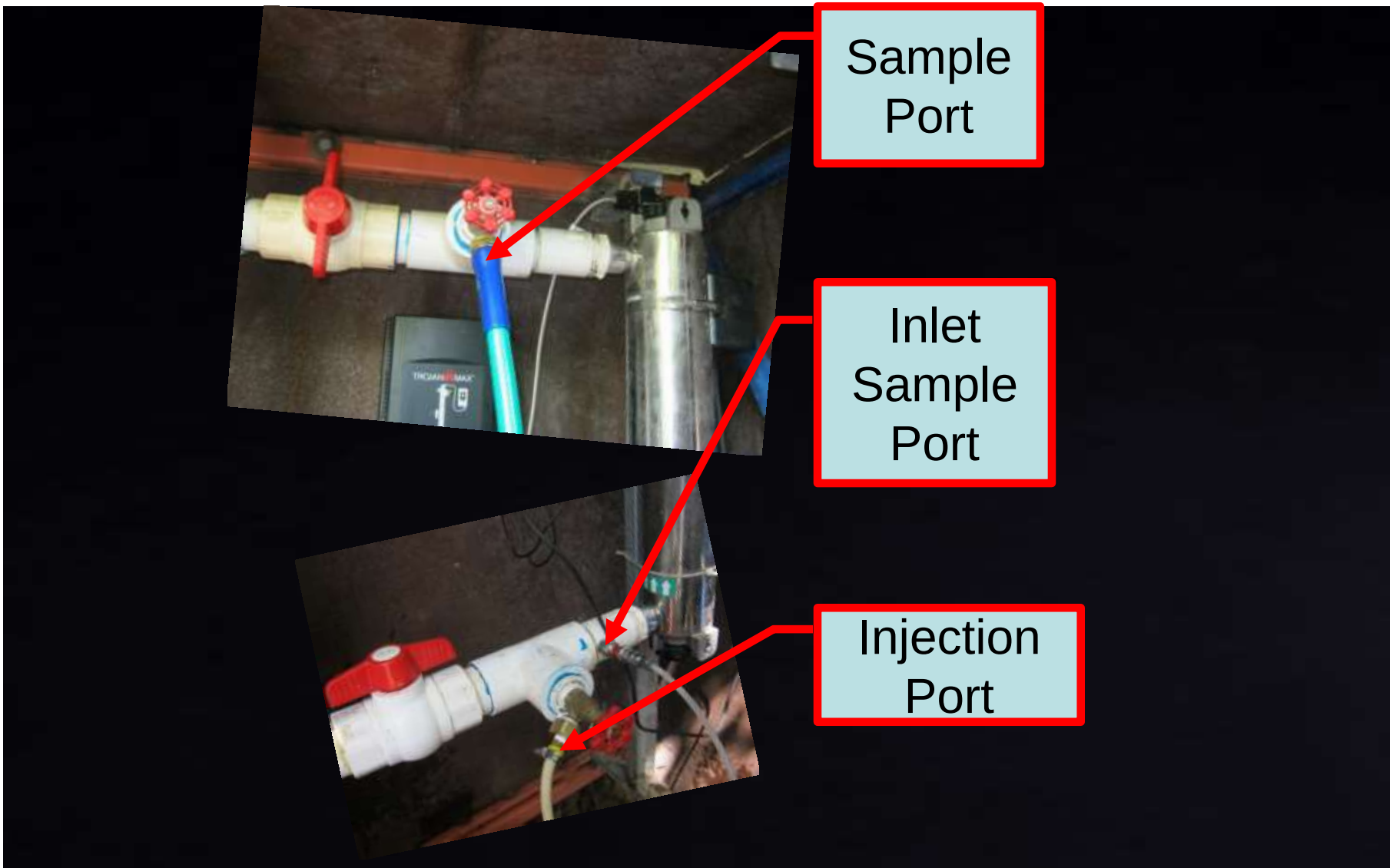


September Test Results for La Sofia

		MS2 (pfu/ML)					
Test No.	Sample Time	Influent	Effluent	Log Reduction	UV Status	Flow Rate (gpm)	UV Dose mJ/cm²
Test1	T0 w/o MS2	3.00E+04 *	0	4.5	UV on	17	--
	T0 w/ MS2	3.00E+04 *	0	4.5	UV on	17	115
	T0 Dup	3.00E+04 *	0	4.5	UV on	17	115
	T30	3.00E+04 *	1	4.5	UV on	17	115
	T30dup	3.00E+04 *	1	4.5	UV on	17	115
	T60	3.00E+04 *	1	4.5	UV on	17	115
Test 2	T0	3.00E+04 *	0	4.5	UV on	7.5	--
	T0 w/MS2	3.00E+04 *	0	4.5	UV on	7.5	115
	T30	3.00E+04 *	0	4.5	UV on	7.5	115
	T30 dup	3.00E+04 *	0	4.5	UV on	7.5	115
	T60	3.00E+04 *	3.00E+04	0.0	UV Off	7.5	--
Test 3	T0	3.00E+04 *	0	4.5	UV on	4.6	115
	T30	3.00E+04 *	0	4.5	UV on	4.6	115
	T30 dup	3.00E+04 *	0	4.5	UV on	4.6	115
	T60	3.00E+04 *	0	4.5	UV on	4.6	115

* - Estimated Test 2, T60 sample. Target concentration: 1.00E+05.

Configuration for April 2014 Tests



April Test Results for La Sofia

		MS2 (pfu/ML)					
Test No.	Sample Time	Influent	Effluent	Log Reduction	UV Status	Flow Rate	UV Dose
						(gpm)	mJ/cm²
Test1	T0 off	1.00E+05 *	0.00E+00	5.0	UV off	15	--
	T0	3.60E+04 *	0	4.6	UV on	15	100
	T15	2.20E+04 *	0	4.3	UV on	15	100
	T15 Dup	2.20E+04	0	4.3	UV on	15	100
	T30	3.00E+03	0	3.5	UV on	15	70
	T30 Off	2.30E+04	2.30E+04 *	0.0	UV off	15	--
	T45 Pump off	0.00E+00	0	--	UV off	15	--
Test 2	T0 off	0.00E+00	1.00E+01	--	UV off	10	--
	T0	7.10E+01	0	1.9	UV on	10	--
	T15	0.00E+00	0	--	UV on	10	--
	T15 Dup	0.00E+00	0	--	UV on	10	--
	T30	7.00E+02	1	2.8	UV on	10	--
	T30 Off	2.70E+04	9.00E+01	2.5	UV off	10	--
	T45 Pump off	3.00E+00	1	--	UV off	10	
Test 3	T0 Off	4.40E+04	3.83E+02	2.1	UV off	5	--
	T0	7.23E+02	0.00E+00	2.9	UV on	5	--
	T15	7.60E+04	0	4.9	UV on	5	115
	T15 Dup	9.20E+04	0	5.0	UV on	5	115
	T30	3.00E+03	0	3.5	UV on	5	70
	T30 Off	3.00E+03	1.40E+04	-0.7	UV off	5	--
	T45 Pump off	0.00E+00	3	--	UV off	5	

* - Estimated from influent stock concentration

Test Results from La Sofia

Conclusions

- At La Sofia, six MS2 viral surrogate studies were completed in September 2013 (17, 7.5 and 4.6 gpm) and in April 2014 (15, 10 and 5 gpm) with UV doses varying between 70 and 115 mJ/cm^2

- With the UV light on, there was an average log inactivation of approximately 4 or 99.99% removal of MS2 with a target influent concentration of 1.00E+05 in the well water source

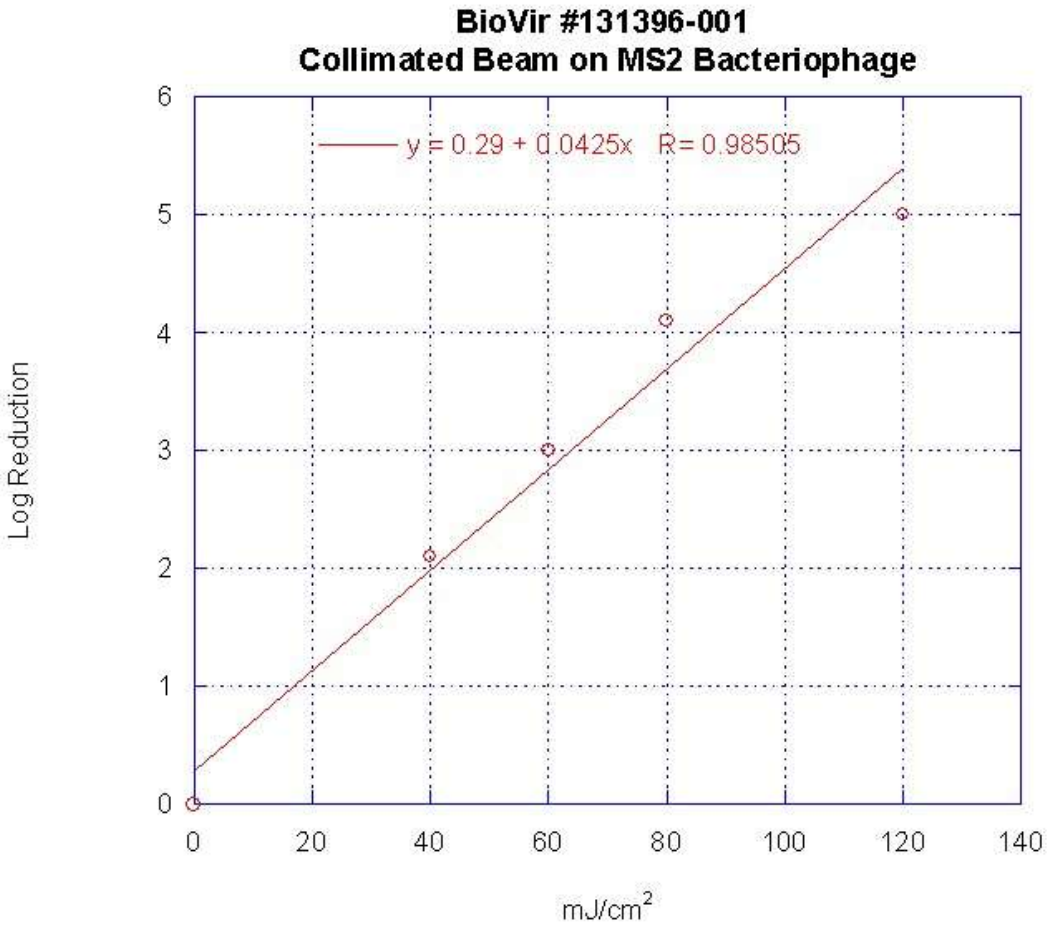
MS2 Studies at Apeadero

Collecting drinking water samples from the raw and treated water

UV System Installation at Apeadero

Apeadero Surface Water

Collimated Beam Results



September Test Results for Apeadero

		MS2 (pfu/ML)					
	Sample Time	Influent	Effluent	Log Reduction	UV Status	Flow Rate (gpm)	UV Dose mJ/cm²
Test 1	T0	4.3E+04	4.3E+04	0.0	UV off	9.3	--
	T0 dup	8.0E+04	8.0E+04	0.0	UV off	9.3	--
	T15	6.20E+04 *	0	4.8	UV on	9.3	110
	T15 dup	6.20E+04 *	1	4.8	UV on	9.3	110
	T30	6.20E+04 *	5	4.1	UV on	9.3	90
Test 2	T0	9.70E+03	9.70E+03	0.0	UV off	7	--
	T0 Dup	7.00E+04	7.00E+04	0.0	UV off	7	--
	T15	4.00E+04 *	0	4.6	UV on	7	115
	T15 dup	4.00E+04 *	0	4.6	UV on	7	115
	T30	4.00E+04 *	1	4.6	UV on	7	115
Test 3	T0	1.00E+05 **	1.00E+05 **	0.0	UV off	4.5	--
	T0 dup	1.00E+05 **	1.00E+05 **	0.0	UV off	4.5	--
	T15	1.00E+05 **	0	5	UV on	4.5	115
	T15 eff	1.00E+05 **	0	5	UV on	4.5	115
	T30	1.00E+05 **	0	5	UV on	4.5	115
Test 4	T0	1.00E+05 **	1.00E+05 **	0.0	UV off	7	--
	T0 dup	1.00E+05 **	1.00E+05 **	0.0	UV off	7	--
	T15	1.00E+05 **	0	5	UV on	7	115
	T15 dup	1.00E+05 **	0	5	UV on	7	115
	T30	1.00E+05 **	0	5	UV on	7	115

* - Estimated from T0 and T0 dup. ** - TMTC; estimated using target concentration of 1.00E+05.

April Test Results for Apeadero

	MS2 (pfu/ML)					
Sample Time	**Influent**	**Effluent**	**Log Reduction**	**UV Status**	**Flow Rate**	**UV Dose**
					(gpm)	mJ/cm²
T0 Off	3.30E+05	3.2E+05	0.0	UV off	5	--
T0	3.50E+05	1.00E+00	5.5	UV off	5	120
T15	3.40E+05 *	0	5.5	UV on	5	120
T15 dup	2.00E+05	0	5.3	UV on	5	120
T30	2.40E+05	0	5.4	UV on	5	120
T30 Off	2.20E+05	2.0E+02	3.0	UV off	5	--
T45 Pump Off	TMTC	TMTC	--	UV off	5	--
T0 Off	2.30E+05	2.30E+05 *	0.0	UV off	4	--
T0	2.10E+05	3	4.8	UV On	4	--
T15	2.10E+05	0	5.3	UV on	4	120
T15 dup	5.70E+04	1	4.8	UV on	4	115
T30	3.80E+05	2	5.3	UV on	4	115
T30 Off	TMTC	TMTC	--	UV off	4	--
T45 Pump off	TMTC	TMTC	--	UV Off	4	
T0 Off	3.10E+05	3.10E+05	0.0	UV off	3	--
T0	3.40E+05	0	5.5	UV On	3	--
T15	3.60E+05 *	5	4.9	UV on	3	120
T15 dup	3.60E+05	0	5.6	UV on	3	115
T30	2.00E+05	0	5.3	UV on	3	115
T30 Off	1.70E+05	TMTC	--	UV off	3	--
T45 Pump off	4.74E+02	7.76E+02	--	UV Off	3	--

Test Results from Apeadero

Conclusions

- At Apeadero, seven MS2 viral surrogate studies were completed on in September 2013 (9.3, 7, 4.5, 7 and 5 gpm) and in April 2014 (4 and 3 gpm) with UV doses varying between 90 and 120 mJ/cm^2
- With the UV light on, there was an average log inactivation of approximately 5 or 99.999% removal of MS2 with a target influent concentration of 1.00E+05 in the surface water source

What about Ease of Use?

UV Quartz Sleeve Maintenance

Cleaning the quartz sleeve with a biocide

UV Intensity Sensor Maintenance

Wiping the sensor lens with alcohol

A clean sensor on the left, A fouled sensor with biofilm on the right

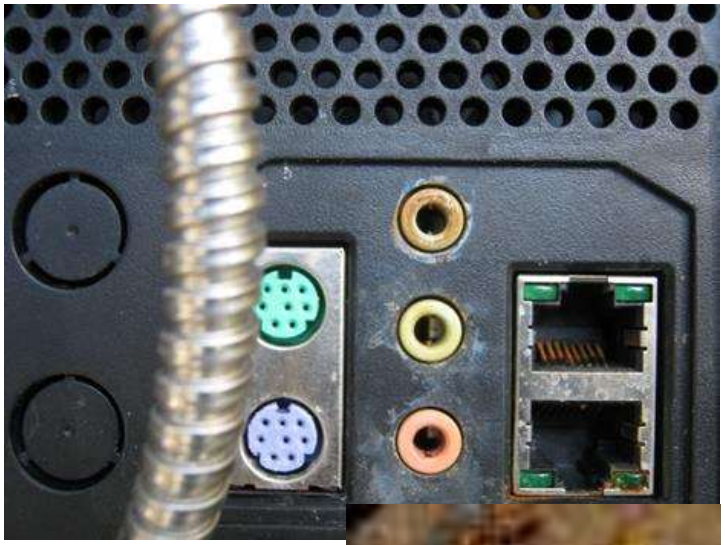
UV Lamp Maintenance

After 6 months, a burned out lamp

Other UV Maintenance Issues

UV power supply mysteriously disappears

Corrosion on electrical contacts



Coqui frogs create a hotel inside settling tubes

Coqui frogs live in UV lamp fan and hitch a ride in back of our SUV

Ants live in UV power supply

Lizards and Coqui frogs eat the ants

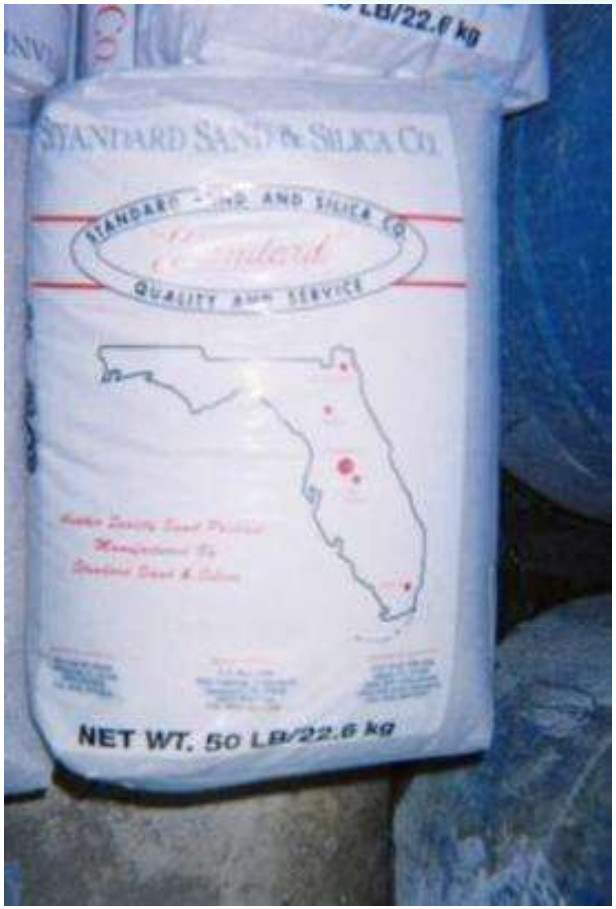
Lessons Learned

Bilingual literature & instructions help but on-site training is the key to community understanding

Lessons Learned

Local assistance keeps the community involved

Lessons Learned



Do not assume that materials will be available on the island. Even media for water filters had to be imported from Florida or sieved by hand from local sources

Lessons Learned

Do not take electrical power for granted. It is unreliable and expensive (>2 times the U.S. average). Well water pumps in Puerto Rico are not used due to the high cost of electricity.

Lessons Learned






Studies may be impeded by U.S. Gov't furloughs, but we made it work!

Conclusions

- Ultraviolet (UV) disinfection, in combination with chlorination, provides a low cost alternative for disinfection of pathogens
- An effective strategy for training on the operation and maintenance of UV treatment systems is as important as purchase and installation
- UV transmissivity was high in the systems we tested (>90%). Therefore, the systems can be generally run without filtration
- However, special precautions are needed in the tropics!

Acknowledgements

- Harvey Minnigh – RCAP, San German, PR
- Rajib Sinha and Lee Heckman – CB&I, USEPA Test & Evaluation Facility, Cincinnati, OH
- Non PRASA water system operators and students from InterAmerican University

There is No End… Questions?

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